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Content-Based Packet Video Forwarding Mechanism in Differentiated Service Networks

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Abstract

To overcome the inherent limitation of the best-effort Internet, differentiated services (DiffServ) for different applications are being embodied by the IETF DiffServ workgroup. The imminent deployment of DiffServ networks will benefit a lot if continuous media applications at the end-systems are aware of their service model. In this paper, we propose a content-based packet video forwarding mechanism where the QoS interaction between video applications and DiffServ network is taken into account. The interaction is performed through a dynamic mapping between the relative priority score (RPS) of each video packet and the differentiated forwarding mechanism. The relative priority is designed to reflect its loss propagation effect for each packet and calculated by merging the relative importance of its component media. Then, the forwarding mechanism provides service differentiation based on the relative QoS requirement of each packet. To verify the efficiency of the proposed strategy, the end-to-end performance is evaluated through packet video transmission over a simulated DiffServ network. The results show that the proposed interaction framework can explore the DiffServ gain efficiently, resulting in enhanced end-to-end video quality.

1. Introduction

Internet applications and customers have very diverse requirements on the network service, making the current best-effort Internet model inadequate. Under the best-effort model, applications at end-systems estimate the network status and adapt to the congestion level by changing the transmission rate and/or dropping packets. A video application may adjust its rate through spatial/temporal quality adjustment in response to packet loss and delay feedback tied with the TCP-friendly congestion control [1, 10]. The other way is to let the network provide a different level of assurance in terms of network QoS parameters within its resource capacity, which can be summarized by the integrated service (IntServ) of the resource reservation protocol (RSVP) and the differentiated service (DiffServ) [2]. Between them, the DiffServ scheme provides a less complicated and scalable solution. In the DiffServ model [2], resources are allocated differently for various aggregated traffic flows. Consequently, the DiffServ approach allows different QoS levels to different classes of aggregated traffic flows. The edge router enables a guaranteed or assured QoS level in a differentiation sense by traffic conditioning such as metering, marking, and shaping/policing. The core router focuses on the forwarding mechanism (i.e. queue management and scheduling) to treat ingress traffic differently. The relatively proportional differentiation [3] is more essential in this region. The service level will be

pre-defined by the service level agreement (SLA) between the service provider and the customer based on the demand of applications.

With the DiffServ-enabled network, delay/loss sensitive continuous media (CM) applications can be built much easily and their scalable realization will become less painful. However, the issue of how to design DiffServ-aware applications is a key factor for its successful deployment. A systematic way to achieve interaction between video applications and the DiffServ network is investigated in this paper, where the relative differentiation concept is emphasized. Sophisticated video compression schemes such as ITU-T H.263+ [4] and ISO/IEC MPEG-4 extensively utilize all kinds of data dependency of video signals, resulting in packets of unequal importance. This feature has been exploited in the unequal error protection scheme, which is widely utilized in the context of error resilient video transmission. In this research, we explore this feature to represent priority levels, called the relative priority score (RPS), so that different video packets can be tied with the proportional loss-rate differentiation of DiffServ networks.

The paper is organized as follows. The QoS Interaction framework is shortly described in Section 2. Video packetization with different priorities according to several criteria is examined in Section 3.1. The proposed content-aware forwarding mechanism in the DiffServ network is detailed in Sections 3.2 and 3.3. The performance assessment by using the *ns* (network simulator) [5] and the error resilient H.263+ stream is given in Section 4, where the implication of experimental results is discussed. Concluding remarks and future work are given in Section 5.

2. Interaction Framework between Video Applications and DiffServ Networks

In Figure 1, the overall diagram of the proposed forwarding mechanism in a DiffServ network is shown, where the service differentiation is mainly provided in terms of loss probability associated with the forwarding queues[1]. Each flow of a user application will first demand its preference in terms of the loss rate by mapping (or marking at the application) the RPS of each packet j to the discrete categories of DiffServ (DS) byte [6], which is indexed by k. It is then classified, conditioned, and assigned (i.e., re-marked) to a certain network DS level, considering the traffic profile from SLA at the boundary region (i.e. at the edge router). Each packet assigned to a queue class will get a specific reliability (e.g., the packet loss rate L_q) by paying price P_q. This differentiation in queuing can be realized by adopting multiple queues with several drop curves known as multiple random early detection (RED) [7] or RED with in and out bit (RIO) [8].

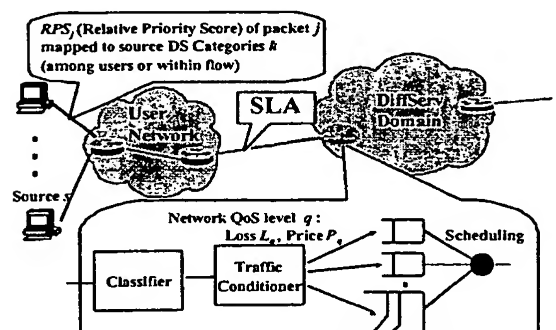

Figure 1: Overall framework of proposed content-based packet video forwarding.

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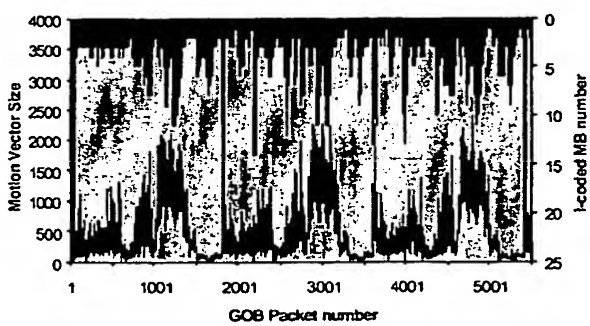
[1] Service differentiation of DiffServ may also support different delays for aggregated flows. However, at this stage, the interaction of packetized video and DiffServ network is analyzed only for proportional loss differentiation.

Given RPS_j for each packet of video, our goal is to explore the best interaction scenario between the RPS-represented video application and the proportionally differentiated network through the content-aware forwarding with several drop precedence and pricing constraints. When assigning packets from each flow to a certain network DS level, two DiffServ scenarios are considered and evaluated through the *ns* combined end-to-end video performance simulation. First, the simplified situation is evaluated, in which every packet of a video flow with RPS is assigned to a single queue with different drop precedence. This result will serve as a justification of our choice on RPS for video packets. It can also reflect the possible gain of content-aware forwarding in the early stage of the DiffServ deployment, where the proportional differentiation is possible only in limited flexibility. In the second scenario, content forwarding is extended to multiple queues, and the approach of feeding a video flow into a single queue is compared to that of flexibly spreading packets to multiple queues.

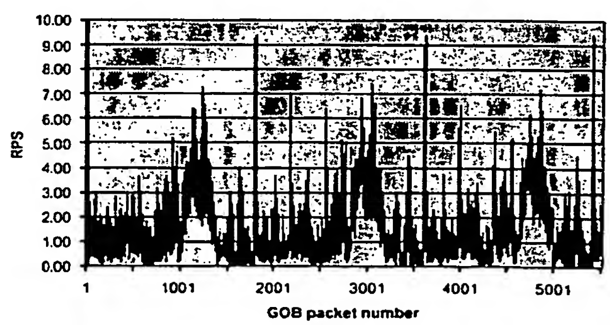
3. Proposed Content-Based Packet Video Forwarding Mechanism

3.1. Relative Priority Score for Video Packet

Under the packetized video transmission, the RPS assignment for a packet would be best if it can precisely represent its error propagation effect to the receiving video quality. For a video stream, a lost packet leads to the content loss of subsequent packets as well as its own, which is caused by the spatial/temporal loss propagation as a result of inter-block/inter-frame correlation. If a media stream is not prepared by taking the possible packet loss into account, the effect can be more severe than expected. For example, 3% packet loss in the MPEG coded bit stream could translate into a 30% frame error rate [9]. Thus, media streaming should be adaptive in adjusting the transmission rate and in selecting proper error resilient features based on the network condition. For example, it may drop frames in a certain preferred order (i.e., in the B-, P-, I-frame order) [11]. Recent research about the corruption model [12], which attempts to model the loss effect of video streams, can also provide a solution for this relative prioritization. However, most modeling efforts up to now have been focused on the statistical side of the loss effect while a dynamic solution is required in our approach.



(a)



(b)

Figure 2: RPS for the 'Foreman' sequence: (a) the motion vector size and the number of I-coded MB in each packet, and (b) RPS based on two video factors.

Hence, as a short-term solution, we propose a simple yet effective RPS scheme for the H.263+ video stream with some error resilient features. Basically, RPS is calculated for each packet corresponding to each GOB of the H.263+ video stream. It takes into account video factors of its component macroblocks (MBs). These factors consist of the MB encoding type (intra, intra-refreshed, inter, etc), the associated motion vectors (MVs), the total size in bytes, and the existence of any picture-level header. That is, RPS represents the summarized level of its component priority levels weighted with their relative importance as

$$\text{RPS (Relative Priority Score)} = \sum_{i=1}^{N_{NVF}} W_i * NVF_i \,, \tag{1}$$

where NVF stands for the normalized video factors and W is the corresponding weight factors, respectively. Currently, we consider two NVF: 1) the normalized MV (motion vector), 2) the normalized I-MB number. The compressed H.263+ video stream is generated at a target rate of 384kbps for a CIF test sequence with 10 fps. Several error resiliency and compression efficiency options ('Annexes D, F, I, J, and T' with random intra refresh) are used in the so-called 'Anchor' (i.e., GOB) mode for the video generation. The random intra-refresh rate is set to 5% to cover the network packet loss. It is then packetized by one packet per each GOB and RPS is assigned by Eq. (1). Figure 2 shows the RPS assignment example for the 'Foreman' sequence.

3.2. Supporting Forwarding Component in DiffServ Network

To assign the relative prioritized video packets to several network DS levels, the priority of each packet is classified and conditioned by thresholding the already categorized RPS (i.e., to map into the DS byte space) as shown in Figure 3. With RPS of each video packet, packet forwarding at the router can do re-mapping under constraints such as loss-rate differentiation and pricing. Following interaction scenarios as discussed in Section 2, it may or may not split video packets of a flow over multiple queues. That is, although Figure 3 is drawn to cover the more general case of multiple queues, it includes the degenerated case of assigning all packets to a single network DS level.

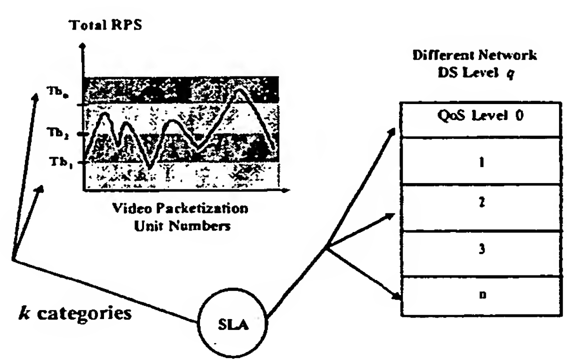


Figure 3: Re-mapping between the DS categorized RPS and the QoS level of a DiffServ network.

The RED/RIO queue management and the weighted fair queuing (WFQ) scheduling provide the differentiated forwarding in our proposed scheme. The chosen WFQ scheduling is currently implemented in many advanced routers since it guarantees each queue to be allocated a fair share of bandwidth irrespective of the behavior of other queues in the same router. As discussed earlier, we consider two network cases: a single queue with a simple modified RIO and multiple queues with RED/RIO and WFQ. To be more specific, for the multiple queue case, five network DS

levels are provided by two assured service (AS) RIO queues and one best-effort (BE) RED queue. These queues are served by WFQ, which is the typical bandwidth weighting scheduler. Its weighting factors are set for the proportional packet loss-rate according to class queues. The RIO queue can provide different packet drop rates by using different RIO parameter settings as shown in Figure 4 [8, 13]. The parameter set includes the minimum threshold, the maximum threshold, and the maximum drop probability (min_th, max_th, P_{max}) for each IN or OUT control curve. The IN control curve provides a less drop probability than the OUT curve according to the average queue length[8].

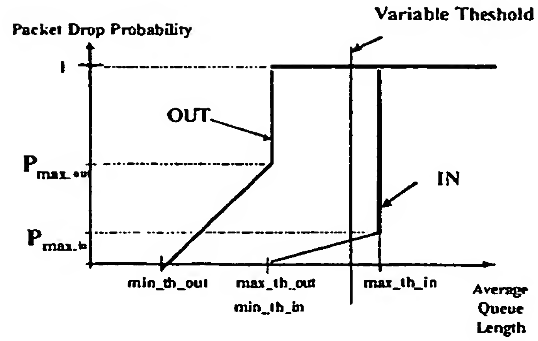


Figure 4: Control parameters of RIO queuing.

3.3. Content-based forwarding for Loss Rate Differentiation

The proposed interaction framework that matches the relative priority of source of the video stream with the loss-rate differentiated DiffServ is stated as follows[2]. Given the bit budget P, the maximum end-to-end video quality (i.e., PSNR or the visual effect) can be obtained by minimizing the quality degradation D

$$\min_{\{u_{k,q}\}} D = \min_{\{u_{k,q}\}} \sum_k e_k \sum_q L_q(u_{k,q})$$

$$\text{subject to } \sum_q p_q \sum_k u_{k,q} \le P \ \text{ for } \sum_q \sum_k u_{k,q} = U, \tag{2}$$

where $u_{k,q}$ is a percentage of the usage measure of the k-th source DS category corresponding to a q-th network DS level. $L_q(u_{k,q})$ is the average packet loss-rate of the k-th category for a video flow when packets are assigned to q level. Also, e_k is the weighting factor to affect the video quality of the k-th category when the portion of packets are lost. P_q is the unit price to use the queuing class q and it can be measured as *\$/kbps*. Finally, U is the total number of bits of a video stream. The above optimization problem is equivalent to the Lagrange multiplier formulation written as

$$\min_{\{u_{k,q}\}} \left\{ \sum_k e_k \sum_q L_{k,q}(u_{k,q}) + \lambda \left(\sum_q p_q \sum_k u_{k,q} - P \right) \right\}.$$

In order to solve the above problem, we have to obtain the following variables. First, P_q depends on the bandwidth portion and its drop control curve of a queue, which will be decided by the service provider and negotiated in SLA. Then, the remaining parameters are e_i and $L_q(u_{k,q})$, given $u_{k,q}$ of a certain video stream. In our case, we can interpret e_k based on the RPS distribution.

[2] We assume that the pricing of each network QoS Tool is proportional to its packet loss rate for video packets through adjusting the target rate or the number of TCP flows artificially or through an intelligent traffic conditioning method.

Also the proportional differentiated service of DiffServ implies that $L_q(u_{k,q})$ is proportional to the q-th choice from higher to lower classes. However, it should be noted that, in order to provide this proportional packet loss-rate $L_q(u_{k,q})$ regardless of the dynamic network load condition, intelligent traffic conditioning with queue management and packet scheduling is required. Finally, for multiple queue cases, one may scatter packets of a single stream over multiple queues. In that case, the cost should incorporate the added complexity cost and out-of-order arrival handling cost at the other end, which is assumed negligible at the current stage.

The single queue scenario – the RPS prioritization effect: In this case, the advantage of prioritization in terms of relevant attributes (e.g. the loss rate in this paper) can be verified, since one should expect better end-to-end quality due to content-based forwarding at DiffServ routers. This situation represents a certain type of user flows, which cannot afford to pay more for the loss of quality. Content-based video classification plays an important role if there exists a pricing constraint. First, each video stream can be assigned to a class of queues according to its pricing level. Then, it gets the enforced target rate that is subject to the worse drop penalty when the rate is exceeded. In fact, the traffic conditioner based on the rather static traffic profile from SLA is not tolerant to burst video flows since it is basically content-blind. By adjusting several thresholds in Figure 3, loss-differentiation can be implemented in this scenario. The amount of data within the target rate will get the desired q level while the overflow portion is forced to lower q levels.

The multiple queue scenario - Interaction of RPS and proportional differentiation: In this case, the RPS distribution of video applications is based on Eq. (2). That is, optimal mapping is attempted without constraining a stream into a single queue any more. It is assumed that the intelligent receiver is capable of correcting negative effects from flow-blind edge or core routers (e.g., out-of-order packet arrival).

Table 1: Given parameters for idealized problem (RPS from 'Foreman' sequence).

k source DS category	e_k Average RPS	u_k Data Percentage (%)
0	0.24748	24.50
1	0.731541	25.04
2	1.416379	24.78
3	2.428823	11.93
4	4.403471	13.76
q network DS level	$L_q(u_k)$ loss rate	P_q Pricing
0	3.5 x u_k	1
1	3 x u_k	2
2	2.5 x u_k	2.5
3	2 x u_k	3
4	1 x u_k	3.5

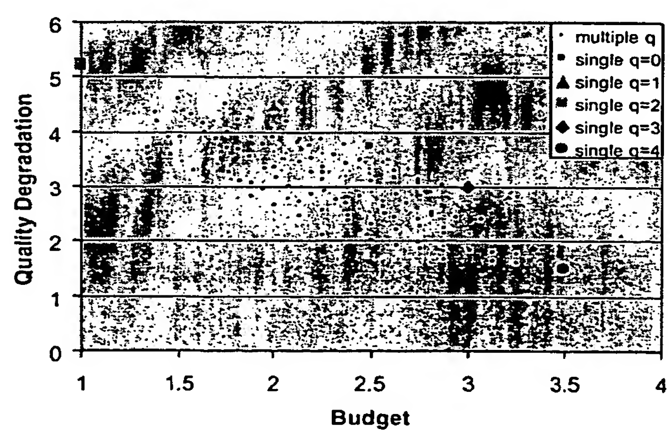


Figure 5: Quality degradation vs. the pricing budget for the idealized problem.

By assuming a pre-defined proportional loss-rate differentiated network, we can get a reference performance of content-aware forwarding. This performance can be viewed as that of an idealized mapping of k categories of a video stream into different q levels to minimize Eq. (2). If RPS used in this reference case is also ideal, it will represent the best end-to-end video quality we can get by employing the content-aware DiffServ forwarding under these constraints. With parameters given in Table I, quality degradation (indicated as the objective index) versus the pricing budget is given in Figure 5. The result shows that a better performance is obtained when higher k categories assigned to higher q levels, rather than the degenerated case where all k categories are concentrated in the same level q (if the budget is permitted). Please pay attention to results of the degenerated cases located in the top area of Figure 5 denoted by the index q of a single queue. On the other hand, the natural mapping that maps to multiple queues based on the relative priority shows a better performance, with which the convex hull of the optimization problem of Eq. (2) can be overlaid. Thus, based on the associated Lagrange multiplier λ, one can find the best mapping for this idealized problem. Experimental results based on *ns*-simulated networks will be described in Section 4.2 and will be analyzed in comparison to the results in Figure 5.

4. Experimental Results

The overall simulation setup for the proposed video and DiffServ interaction is illustrated in Figure 6. The test video trace with RPS is transmitted employing UDP over the *ns*-simulated DiffServ network as shown in Figure 7. The routers R0 ~ R3 are DiffServ-enabled with several network DS levels by using RIO and WFQ. When the video flow starts to compete with other TCP flows, error resilient decoding is applied to corrupted streams. The network is conditioned by different packet drops ranging from 0 to about 10%, which is controlled by the number of best-effort TCP flows and the setting of different target rates in AS queues.

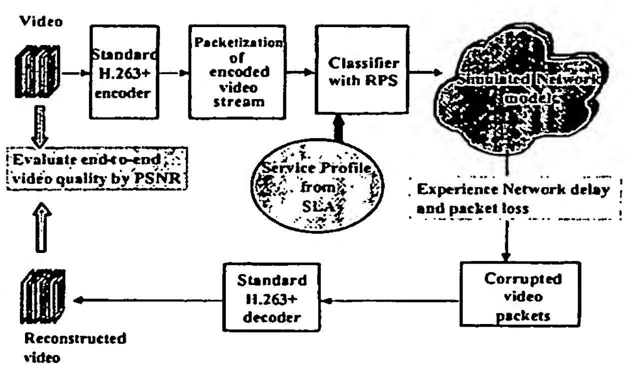


Figure 6: The overall simulation diagram for video applications in a DiffServ Network.

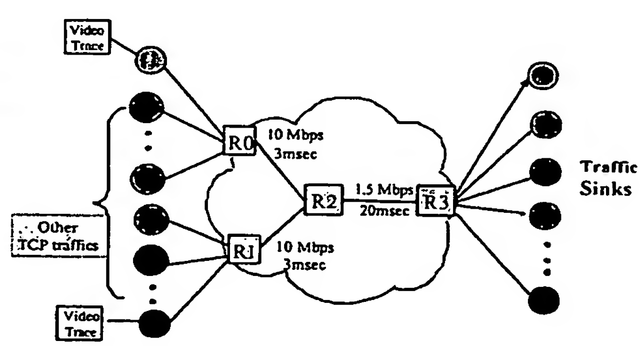
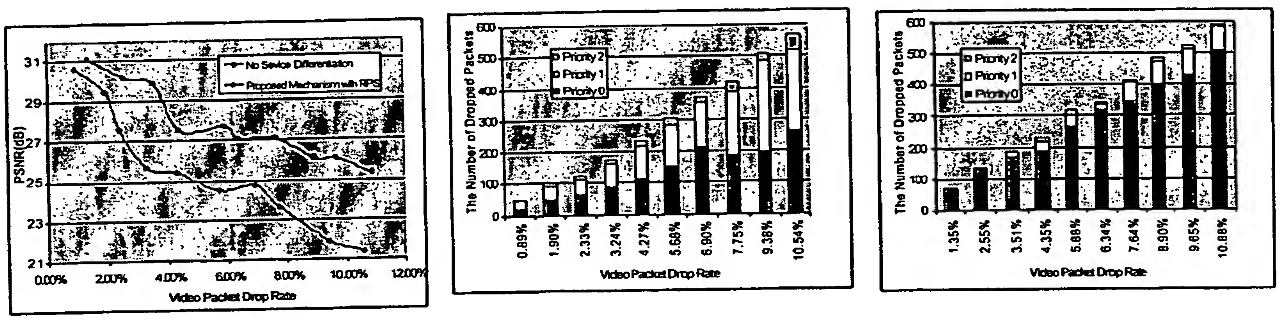


Figure 7: Network Model for Simulation.

Before going into details of performance evaluation, it is worthwhile to point out that the matching of relative prioritized video packets and network adjustment is dynamic in nature, while SLA can only provide the guideline in a static manner. In other words, it means that the *ns*-based simulation in its current form is not sufficient in representing the real-world situation in the full capacity. However, to demonstrate the source-network interaction concept in the DiffServ scenario shown in Figure 1, the interaction simulation setup as shown in Figures 6 and 7 is acceptable.

4.1. Service Differentiation with RPS in Single Queue System



(a) (b) (c)

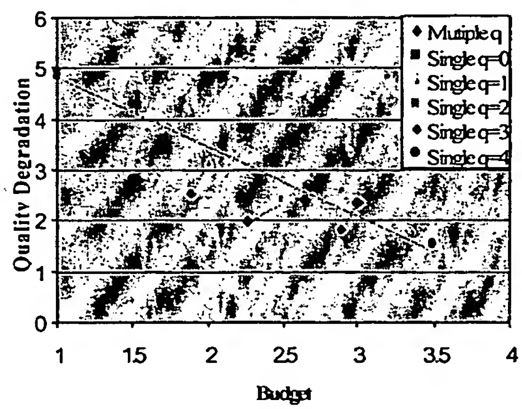
Figure 8: The performance comparison of the 'Foreman' sequence under the single queue scenario: (a) the video packet drop rate vs. the average PSNR for 300 frames. The number of dropped video packets in a network with (b) no service differentiation and (c) the proposed mechanism with RPS, where the total packet numbers/average byte of each class are 2675/205.8, 2381/204.5 and 351/243.2 for priority classes 0, 1 and 2, respectively.

In this experiment, one of three different service classes is assigned to each video packet from one video trace by comparing RPS with two threshold values. Then, these packets are served by using different threshold combinations for RIO (*max_th_in* in this case). That is, IN and OUT parameters of the RIO queue is adjusted so that different drop probabilities and throughput performances are provided. The end-to-end video quality is measured in terms of PSNR. We compare results of RPS differentiation with that of using the RED queue only (without RPS differentiation). In Figures 8(b) and (c), the effect of packet drop rates is compared for RPS video packets. It is clear that a higher RPS value results in a smaller drop rate, which enhances the performance in comparison to no service differentiation. The gain of the proposed mechanism with RPS in terms of end-to-end video quality is also shown in Figure 8(a), where the PSNR gap increases as the network drop rate increases.

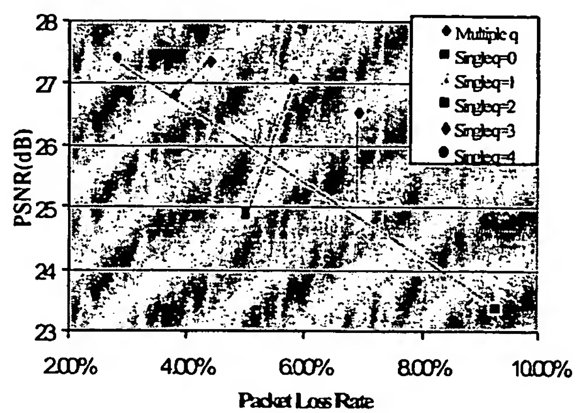
4.2. Service Differentiation with RPS in Multiple Queue System

The *ns*-simulated evaluation of the multiple queue case is performed in this section. In this case, there are three queues in each router R0 ~ R3. The AS1 queue having RIO are associated

with two levels q= 3 and 4, AS2 having RIO with q=1 and 2, and BE queue having RED with q=0. Weighting factors of WFQ are set for the above queues as AS1:AS2:BE = 2.25:2:1.75. In order to get a fair comparison with the degenerated case, we injected two video traces simultaneously and assigned one trace to the fixed single queue and the other trace to any queue. The dotted line (---) in Figure 9 shows these two video traces to compare, with the exceptional case of single q=0 and q=4. Figure 9(a) is obtained by calculating Eq. (2) but with the actual packet drop rate of each q from the *ns* simulation. It shows a similar trend, where middle cases (i.e., mixing single and multiple q levels) are closer than that of Figure 5. This implies that the actual packet loss rate among q level is not proportional as the ideal case of Table I, which indicates the limit of simple RIO/RED and WFQ in providing the proportionally differentiated forwarding. This is one of the future work, in which we will explore the adaptive queue management and the scheduling scheme based upon network load dynamics. Finally, Figure 9(b) shows differentiation results in terms of PSNR, the end-to-end video quality, which shows the clear correspondence with Figure 9(a). Multiple q cases get better PSNR than single q cases, even though single q cases spend more pricing budget(corresponding to lesser total packet loss rate).



(a)



(b)

Figure 9: The performance comparison of the 'Foreman' sequence under multiple-queue scenario: (a) the quality degradation vs. the pricing budget, and (b) end-to-end video quality vs. network packet loss.

5. Conclusion

A content-based packet video forwarding mechanism was proposed in this work, in which QoS interaction between video applications and DiffServ-enabled networks was considered. The proposed RPS plays a good bridging role in enabling the network to be application-aware and provide better end-to-end video quality by using the same network capacity. The performance of content-aware differentiation has been demonstrated in terms of the packet drop probability and the throughput. Experimental results showed that the proposed framework has enhanced the end-to-end video quality at the same packet drop rate.

A couple of areas in this proposed framework has to be elaborated furthermore and is under our current investigation. First, only the differentiation of loss-rates is performed in this work and it has to be extended to cover the other key QoS factor, i.e. delay. The loss-rate/delay combined differentiation will provide a more comprehensive characterization of the media priority (for the video stream itself as well as among various multimedia traffics). Thus, by summarizing loss-rate and delay priorities in the DS byte of the packet header, more enhanced content-aware forwarding will be feasible so that the network is able to handle incoming video packets more intelligently. Second, the assignment of relative priority is still very simple in this work, and it requires more elaboration. For example, we can add more factors such as dependency counts [14] for the priority in terms of the packet loss preference. We can also translate the corruption model into a dynamic prioritized solution. Finally, for the multiple-queue case, we can explore the forwarding method for proportional differentiation in depth. Also, it is interesting to add the cost of distributing a flow stream into multiple queues.

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